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Integrating bioenergy into computable general equilibrium models — A survey

Bettina Kretschmer *, Sonja Peterson

Kiel Institute for the World Economy, 24100 Kiel, Germany

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ABSTRACT

In the past years biofuels have received increased attention since they were believed to contribute to rural development, energy security and to fight global warming. It became clear, though, that bioenergy cannot be evaluated independently of the rest of the economy and that national and international feedback effects are important. Computable general equilibrium (CGE) models have been widely employed in order to study the effects of international climate policies. The main characteristic of these models is their encompassing scope: Global models cover the whole world economy disaggregated into regions and countries as well as diverse sectors of economic activity. Such a modelling framework unveils direct and indirect feedback effects of certain policies or shocks across sectors and countries. CGE models are thus well suited for the study of bioenergy/biofuel policies. One can currently find various approaches in the literature of incorporating bioenergy into a CGE framework. This paper gives an overview of existing approaches, critically assesses their respective power and discusses the advantages of CGE models compared to partial equilibrium models. Grouping different approaches into categories and highlighting their advantages and disadvantages is important for giving a structure to this rather recent and rapidly growing research area and to provide a guidepost for future work.

1. Introduction

In the context of energy security and climate protection, bioenergy is ascribed high importance. Especially biofuels have received increased attention since they are able to replace fossil energy in the transport sector. As the transport sector is contributing an increasing share to global carbon emissions they are seen as an important mitigation option, also because other renewable energy sources usually only replace fossil fuels in the electricity (wind, hydro, photovoltaics) or in the heat sector (wood pellets, geothermal energy, solar thermal energy). Currently, only Brazil is able to produce bioethanol from sugar cane at sufficiently low costs to be competitive with conventional fuels. Nevertheless and for reasons just explained, bioenergy and biofuels are part of climate and energy policy packages in several countries and supported by quotas, tax exemptions or direct production subsidies. This has resulted in growing production and consumption of biofuels worldwide. Plans to further increase the use of bioenergy are on the table.

In Europe, the directive on the promotion of the use of energy from renewable sources (henceforth RES directive) targets a 20% share of renewables — including bioenergy — in total energy use in 2020 and additionally imposes a 10% minimum share of renewable energy in transport (cf. European Union, 2009). Without the widespread availability of alternative renewable transport fuels, these will primarily be biofuels. A crucial element of the RES directive is that both domestically produced and imported biofuels need to meet sustainability criteria. Furthermore, the binding character of the 10% quota is subject to biofuels being produced sustainably and second-generation biofuels becoming commercially available. In 2007, the EU share of biofuels in total fuel consumption was 2.6% corresponding to an estimated combined EU ethanol and biodiesel consumption of 9.9 billion litres. Thus big efforts have to be undertaken in order to reach the 10% target in 2020, which would approximately correspond to a biofuel use of 22.8 billion litres as projected by the European Commission.[1]

The 2007 US Energy Independence and Security Act (EISA) stipulates that by 2022, 36 billion gallons (ca. 136 billion litres) out of total transportation fuels used shall be biofuels. Out of that, 15 billion shall be conventional biofuels, which will mostly be corn-based ethanol. This requires a substantial increase from a 2008 ethanol production of 9 billion gallons. The remaining 21 billion shall be advanced biofuels, including biodiesel as well as cellulosic fuels.[2] US ethanol production has even overtaken Brazilian ethanol production recently.

Other countries also pursue their own policies in promoting the use and production of biofuels, among them China and India.[3] All these

[1] EurObserv'ER (2008) and European Commission (2007) for projected biofuel use in 2020 (converted to litres).

[2] United States. Cong. Senate (2009). 110th Congress, EISA 2007. For ethanol statistics, see RFA (2009).

[3] For an overview of biofuel policies in OECD countries see OECD (2008). Koizumi and Ohga (2007) discuss the impacts of biofuel policies in Asia.

* Corresponding author. Tel./fax: +49 431 8814 228/500.
E-mail address: bettina.kretschmer@ifw-kiel.de (B. Kretschmer).

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developments indicate a strong rise in biofuel production over the next years. The governmental support for bioenergy has been heavily criticized especially in the context of rapidly rising food prices in 2007/2008. A heated 'food vs. fuel' debate has emerged that reflects the fear that enhanced biofuel production may lead to enormous land use competition that would drive up agricultural product and food prices. It is therefore vital to get a better understanding of the economy-wide impacts of enhanced bioenergy production and especially its impact on land use competition and on agricultural and ultimately food prices.

There are thus two essential dimensions that the study of bioenergy has to take into account: (1) Biofuels should be studied from an international perspective given worldwide biofuel support policies and the likely reliance on imports for fulfilling mandatory biofuel quotas. (2) One has to analyse economy-wide effects as suggested by the impacts of biofuel production on the agricultural and food sectors but also on other sectors of the economy, e.g. on the energy sector to name only one. Computable general equilibrium (CGE) models have been widely employed in order to study the effects of international climate policies (see e.g. Springer, 2003). The main characteristic of these models is their encompassing scope: Global models cover the whole world economy disaggregated into regions and countries as well as diverse sectors of economic activity. Such a modelling framework unveils direct and indirect feedback effects of certain policies or shocks across sectors and countries. CGE models are thus well suited for the study of bioenergy policies.

This paper focuses on different approaches to include bioenergy into CGE models, the advantages and disadvantages of these approaches and implications for future modelling work. In this course we also try to compare and explain major results of different models. Included in this paper are all major multi-region CGE models we are aware of that include bioenergy. These are in particular the models USAGE (Dixon et al., 2007), a GTAP-E version modified at LEI Institute (Banse et al., 2008), WorldScan (Boeters et al., 2008), DART (Kretschmer et al, 2008), EPPA (Reilly and Paltsev, 2007; Gurgel et al., 2007; Melillo et al., 2009) and augmented versions of GTAP (Birur et al., 2008; Hertel et al., 2008; Keeney and Hertel, 2009). Besides CGE models there are of course other types of models suitable for studying bioenergy. Indeed, many studies to-date have used partial equilibrium (PE) models (see Gerber et al., 2008) that mostly focus on the agricultural sector. It is beyond the scope of this paper and also not the aim to provide a detailed survey of modelling bioenergy in PE models. A report that goes into this direction and includes a number of PE models is by Pérez Domínguez and Müller (2008) while Gerber et al. (2008) compare the results of different models with respect to effects of biofuel policies on food prices. Yet, to make the strengths and weaknesses and the limitations of the CGE approach more transparent we also include a section on PE models and their analysis of bioenergy policies.

The data base of CGE models are so-called social accounting matrices (SAMs). A SAM is a balanced matrix that summarizes all economic transactions taking place between different actors of the economy in a given period, e.g. one year. Economic transactions are represented in value terms and the SAM is balanced in the sense that the value of, for instance, a production sector's output equals the value of its inputs, although SAMs can be much more detailed than that including taxes, subsidies, transfer payments etc. It is assumed that a SAM for a certain year represents an equilibrium of the economy and the model is calibrated in such a way that the SAM is a result of the optimizing behaviour of firms and consumers in the model. The Global Trade Analysis Project (GTAP) provides every few years new consistent international SAMs that are used by basically all global CGE models. The most recent data base GTAP7 was published in October 2008 (Narayanan & Walmsley, 2008) and is based on input–output and trade data for the year 2004. Many models still run on GTAP6 with 2001 as the base year (Dimaranan, 2006). The problem is that there was only little production of bioenergy until recently and that the SAMs used for the calibration of existing models thus give little information on the production and trade patterns of bioenergy that begin to emerge today. Fig. 1 shows the development of biofuel production in the major producing countries and nicely illustrates the fact that biofuel production in the USA and the EU only really took off after 2001. Brazil on the other hand already had an important ethanol industry much earlier. In addition, even if some production and trade existed in a certain base year, it is not shown explicitly in the SAMs, but aggregated e.g. to total fuel use. Furthermore, current bioenergy production is mainly the result of a variety of different governmental support measures that are neither — at least not explicitly — included in the SAMs yet. Future production and trade patterns are likely to look very different from today's patterns and depend crucially on policy assumptions. Thus, there is a general lack of consistent production and trade data for bioenergy and biofuels.

Hence, the general challenge in modelling bioenergy is that, on the one side, bioenergy is not a production sector that is included in the base year SAMs of CGE models, so that it cannot be calibrated in the usual way. On the other side, it is also not a pure future technology but one has to account for the production and trade patterns that exist today as a result of governmental support. One can currently find various approaches in the literature to overcome these difficulties and to incorporate bioenergy into a CGE framework. This paper intends to give an overview of existing approaches and to critically assess their respective power. Grouping different approaches into categories and highlighting their advantages and disadvantages is important for giving a structure to this rather recent and rapidly growing research area and to provide a guidepost for future work.

The paper is organized as follows: We first compare the advantages and disadvantages of general and partial equilibrium models in Section 2 and discuss general modelling issues in the context of biofuels in Section 3. Section 4 describes the first type of modelling approach that we distinguish, the *implicit approach*, which is a rather ad-hoc approach that avoids an explicit modelling of bioenergy production technologies but instead prescribes the amount of biomass necessary for achieving a certain production level. Section 5 deals with a second category of models that include biofuel production with the help of so-called latent technologies. These are production technologies that are existent but not active in the base year of the model and that can become active at a later stage or in counterfactual scenarios. Section 6 outlines the third approach that intends to actually disaggregate bioenergy production sectors directly from a social accounting matrix (SAM), the underlying data structure of CGE models. Section 7 summarizes results with respect to agricultural price effects across studies and Section 8 concludes.

2. Comparing partial and general equilibrium approaches

Besides general equilibrium (GE) models the second class of models that is used to assess the implications of extended bioenergy production are partial equilibrium (PE) models that focus in most cases on the

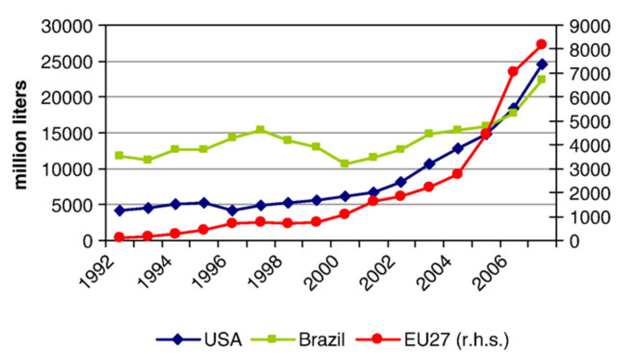

Fig. 1. Historical production of ethanol in USA and Brazil and of total biofuels in EU27. Sources: RFA, 2009; UNICA, 2009; Biofuels Platform, 2009.